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Treatment of Heavy Metal Contaminated Waste

Donald M. Cropek, Jean Day, Debbie Curtin, and Patricia A. Kemme

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Foreword

This study was conducted for the former U.S. Army Installation Support Center (ISC) under Military Interdepartmental Purchase Request W26HBF82734161, Work Unit WQ8, "Treatment of Heavy Metal Contaminated Waste." The former ISC is now part of the U.S. Army Corps of Engineers, Directorate of Military Programs. The technical monitor was Bob Fenlason, CEMP-RI.

The work was performed by the Environmental Processes Branch (CN-E) of the Installation Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. Donald M. Cropek. The technical editor was Linda L. Wheatley, Information Technology Laboratory. Dr. Ilker R. Adiguzel is Chief, CN-E, and Dr. John T. Bandy is Chief, CN. The associated Technical Director was Gary W. Schanche, CVT. The Acting Director of CERL is William D. Goran.

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1 Introduction

Background

Heavy metal (HM) contaminated waste is a major concern to Army and Department of Defense (DoD) installations due to the total volume and number of sites with this type of waste. The U.S. Environmental Protection Agency (EPA) strictly regulates the disposal and treatment of hazardous waste under the Resource Conservation and Recovery Act (RCRA), which classifies the HM-contaminated waste as hazardous by either definition (e.g., listed) or characteristic. Heavy metals of concern under RCRA are (in approximate order of decreasing importance to the Army): lead, chromium, cadmium, mercury, arsenic, silver, barium, and selenium. Types of wastes that may be contaminated by HM include soil, sludge, paint blast media, and ash as well as process waste streams. If these wastes fail the Toxicity Characteristic Leaching Procedure (TCLP) (EPA 1990), they are deemed a hazardous waste by characteristic. The TCLP is a test procedure developed by the EPA to determine the leachable contaminant content of a sample, including different organic and metallic species. Depending on whether the waste has a leachable metal concentration below or above the TCLP limit, the waste is said to either "pass" or "fail" TCLP, respectively. Disposal of hazardous waste regulated federally and/or by state and local laws can be extremely costly.

The problem with HM-contaminated wastes is the ability of the HM to leach from the waste into any solution it contacts. A common example is rainwater passing through contaminated soil. The rain can leach out HMs from the soil thus making them bioavailable to flora and fauna. A second example is the consumption of lead-contaminated paint chips and dust by children. Stomach acid is sufficient to leach lead from the paint chips, making it available to enact its toxic effects upon the human body. The key characteristic, therefore, of an HM waste is not the total metal content but the leachable metal concentration. The TCLP method is designed to simulate the environmental conditions that determine the hazardous nature (leachability) of the material.

Of particular concern is lead-based paint (LBP). Under the authority of the Consumer Product Safety Act, lead was banned in paint for consumer use in 1978.

In 1992, the Residential Lead Based Paint Act (Title X) mandated the elimination of the LBP in government-owned housing structures. The Army maintains 270 million square feet of family housing of which 65 percent (264,000 structures) are more than 25 years old and assumed to have both interior and exterior surfaces painted with LBP. Hence, there exists a huge potential source of HM-contaminated waste streams such as sludge and paint blast media from the remediation and removal of these structures. The soil surrounding and underlying structures and playgrounds on Army installations can be contaminated by the leaching of lead from LBP.

HM-contaminated soils are also a particular problem for an installation affected by base realignment and closure (BRAC). The contamination can occur from LBP abatement procedures, runoff from lead tiled roofs or copper flashing, military training activities (e.g., firing ranges), etc. According to EPA, any soil containing >5000 ppm total lead must be abated by removal, replacement, or construction of permanent barriers to contain the site. Lead-contaminated soil is a RCRA-classified hazardous waste. Therefore, stabilizing the soil before excavation will allow it to pass TCLP so that it can be disposed of less expensively as a nonhazardous waste. Another example is the incineration of items containing HM, for instance, metal catalysts in propellant formulations. Incineration can eliminate much of the matrix but concentrates the metal in the baghouse ash. Sludge produced from industrial processes such as electroplating has very high levels of chromium. Painting and de-painting operations generate sludge and blast media high in metal content.

Cleanup, remediation, and compliance efforts all have programs actively researching the treatment and alleviation of HM problems. However, these efforts are largely experimental in nature and have a high risk factor, long development times, and potentially limited application. Situations such as BRAC and Superfund sites require immediate solutions. The private sector has spent many research and development dollars to develop and refine treatment methods for "off-the-shelf" HM treatment products that may satisfy the Army's immediate requirements. Many of these products may be applicable to a wide variety of contaminants in difficult matrices or they may be limited to a single metal in a unique situation. The difficulty lies in matching the problem with the best available solution.

Chemical treatment methods focus on reducing the leachable metal fraction so the waste can be reclassified as nonhazardous. A chemical reaction transforms the metal from a leachable form to a nonsoluble metal compound. In this instance, nonleachable is equivalent to nonhazardous. A treated waste will have a leachable metal concentration that is below the TCLP regulatory limit and, therefore, can be disposed of in a less expensive manner or, in many instances, left onsite.

Stabilization of a waste means to decrease, limit, or eliminate the solubility or mobility of a contaminant in the waste without changing its physical characteristics. Solidification of a waste indicates the production of a solid block of the waste with high structural integrity that may also serve to limit the mobility of contaminants within the waste. According to Barth et al. (1990), stabilization/solidification (S/S) of hazardous wastes involves three steps:

1. improve the handling and physical characteristics of the waste
2. decrease the surface area of the waste to limit leachability of contaminants
3. decrease the solubility of the hazardous constituents of the waste.

Either a physical encapsulation mechanism or a chemical reaction can stabilize HMs to prevent leaching into surrounding media.

Objective

The objective of this work was to evaluate off-the-shelf vendor products for their ability to stabilize HMs in different contaminated media. An installation with a particular HM contamination problem can look to this report to determine if a solution already exists for a specific metal in a specific matrix. This work will also indicate product limitations and applicability. An installation can use CERL's expertise as an independent testing facility to evaluate and characterize a waste, perform stabilization experiments to find the best vendor product, and provide recommended solutions to treat the HM contamination problem.

Approach

Vendor stabilization products were collected, evaluated, and tested on a range of standard HM-contaminated wastes, and then ranked according to several criteria. These criteria include stabilization effectiveness for each metal, ease of use, weight gain, versatility, pH changes, and form of the end product. This information can then be provided to installation customers so that they can match their particular contaminated waste with an effective stabilizing technology.

Scope

Interpretation of this work should be made based solely on the method of conducting the test. No attempt was made to do an exhaustive investigation into successful stabilization of all HM wastes or successful use of each vendor product. Generic forms of the vendor product were used without further optimization. Only HM-contaminated solid wastes were tested, not wastewater containing HM. The conclusions drawn and rankings made from this work do not reflect other possible products a vendor may manufacture.

Mode of Technology Transfer

The findings of this research will form the basis for providing a Center of Expertise to customers. The Center will provide a match for the most cost-effective and efficient off-the-shelf vendor product to stabilize heavy metals in different contaminated media. It is recommended that the findings of this study be transferred to potential users through conference presentations, DoD, MACOM, and installation publications.

2 Experimental Parameters

Samples

Eight standard samples containing RCRA-regulated metals in varied matrices and concentrations were purchased from Resource Technology Corporation (RTC, Laramie, WY). Specific information concerning these standard wastes is listed in Table 1. The values in Table 1 are certified total metal concentrations, except for samples CRM202, CRM203, CRM206, and CRM208, which are certified leachable metal concentrations from TCLP studies. All samples were used as received.

The standard wastes were chosen to provide at least one waste containing a high total or leachable concentration of each RCRA metal. Due to known problems in the field and the ubiquitous nature of some metals, aluminum, nickel, and zinc were also included in the tests. The more important characteristics of each waste are shown in bold print in Table 1. For each of the 11 metals, at least 1 waste had a very high concentration. The wastes were also chosen to provide several different media, specifically: sludge, soil, ash, and paint.

Table 1. Certified standards of HM-contaminated waste with corresponding concentrations of HM (ppm).

Sample	Matrix	Al	As (5.00)	Ba (100.0)	Cd (1.00)	Cr (5.00)	Pb (5.00)	Hg (0.200)	Ni	Se (1.00)	Ag (5.00)	Zn
CRM018	Raw Sewage	**22,436**	**6.63**	**1,103**	5.57	**40.1**	**126**	**4.78**	20.4	**8.38**	**72.1**	**1,121**
CRM006	Paint Sludge	73.4	-	**9,969**	**32.4**	11.1	**753.0**		-	-	-	**737,431**
CRM013	Paint Chips	-	-	-	**37.8**	**617.6**	**643.2**	-	-	-	-	-
CRM012	Incinerator Ash	2,160	-	18.7	**361.6**	**161,517**	**120.1**	-	**13,279**	-	**54.8**	**634.7**
CRM020	Dry Soil	1,755	**400**	24.8	15.4	13.6	**5,111**	**1.12**	16.9	**6.57**	**38.5**	**3,011**
CRM025	Soil	**7,637**	**339**	**1,839**	**369**	**441**	**1,447**	**99.8**	12.2	**518**	**132**	51.8
CRM202	Superfund Site Soil	-	1.44	5.85	**19.61**	**11.10**	**48.54**	**5.58**	-	**1.38**	**5.01**	-
CRM203	Ash	-	<0.1	<0.5	**22.5**	<0.1	**14.3**	<0.001	-	<0.1	<0.1	-
CRM206	Soil	-	**13.99**	0.38	8.34	0.13	2.16	**0.65**	-	**20.55**	1.04	-
CRM208	Soil	-	3.93	**32.8**	**46.7**	0.87	2.14	**0.62**	-	ND*	ND	-
S2	Clean Soil	3,540	2.00	50.00	ND	ND	ND	0.03	ND	0.40	ND	21.30

Note: Certified reference materials CRM018, CRM006, CRM013, CRM012, CRM020, and CRM025 list total metal content while CRM202, CRM203, CRM206, and CRM208 list leachable metal concentrations from TCLP testing. The TCLP limit is shown in parentheses. Wastes with leachable values above the limit are deemed hazardous. Values in bold represent metal levels expected to provide a rigorous test for the stabilization products.

* ND indicates that the heavy metal was not detected; - indicates this value was not reported

Al = aluminum; As = arsenic; Ba = barium; Cd = cadmium; Cr = chromium; Pb = lead; Hg = mercury; Ni = nickel; Se = selenium; Ag = silver; Zn = zinc

Vendor Products

A search for vendor products began by reviewing Internet sites and literature for companies that manufacture specialty chemicals for stabilizing HM. The identified manufacturers were contacted and informed of this evaluation project. If the manufacturer had a product that would stabilize HMs in a solid matrix, a sample of the product was requested. Only two companies elected not to participate in this testing and declined to provide samples for evaluation.

It was surprising how few products are available to chemically immobilize HM. Fourteen products were collected from seven different vendors. To prevent controversy and to prevent any semblance of promoting one product over another, the vendor products are not identified and are labeled as Products A through N. In addition, two products were tested that are not specifically designed for HM stabilization. Portland (Type II) cement is frequently used as an S/S matrix. Due to its low cost, commonality, and general effectiveness, this product provides a good baseline to contrast with the other products. Since Portland cement works well, another specialty cement with the dual benefits of faster drying and higher compressive strength was also tested and is labeled as Cement 2.

Reagents

Sodium hydroxide (Aldrich, Milwaukee, WI, 97%), nitric acid (Fisher, Pittsburgh, PA, trace metal grade), and glacial acetic acid (Fisher, trace metal grade) were used as received to make the TCLP extraction solution of pH 4.93 +/- 0.05 outlined in SW-846 Method 1311 (EPA 1990). The water used during preparation of the solution was deionized with a Milli-Q Plus system (Millipore Systems, Bedford, MA). Nitric acid was used for the microwave digestion method outlined in SW-846 Method 3015A (EPA 1998).

Sample Preparation and Leaching Test

The products were used in accordance with instructions furnished by the company although quantities were scaled back for bench scale testing. Approximately 2 grams of standard waste was used in each experiment together with an appropriate amount of a stabilization product. After treatment, all samples were cured for 24 hours before leach testing. As per convention, the Portland cement samples were also dried for 30 days before TCLP testing. The extraction fluid was added to the samples based on the ratio of 20 mL of fluid to 1 gram of solid waste. In general, 40 mL of extraction fluid was used for a 2 gram sample of the stabilized solid product. Extraction proceeded for 18 hours under agitation. The TCLP samples were centrifuged for 5 minutes to promote better separation and collection of the extract by gravity filtration using #40 Whatman filter paper.

The collected extract was then digested via microwave using a CEM Model MARS5 microwave (Hilliard, OH) as per SW846 Method 3015A (EPA 1998). The microwave digestion method consisted of adding 4 mL of nitric acid to 40 mL of the TCLP leachate. Heating to 160 °C then digests the solution for 10 minutes followed by an additional digestion step of heating to 170 °C for another 10 minutes.

Atomic Absorption (AA) Analysis

A Perkin-Elmer (Norwalk, CT) 3030B atomic absorption instrument analyzed the TCLP extracts for lead, chromium, cadmium, silver, barium, zinc, nickel, and aluminum. The flame conditions were optimized separately for each metal. All of the metals except Al and Ba used an acetylene/air flame. Al and Ba used a hotter nitrous oxide/acetylene flame and a 0.1% addition of potassium chloride solution to minimize interferents. Instrument performance and calibration curves for each metal were ascertained with independent standards of each metal.

Requirements for specialized instrumentation for the volatile metals arsenic, mercury, and selenium, meant these metals were analyzed by an independent outside laboratory with a Perkin-Elmer Sciex Elan 6000 ICP/MS. To minimize expense, only samples that reported significant total or leachable concentrations of arsenic, mercury, or selenium were sent for analysis. The calculated detection limits are 0.05 ppm lead, 0.01 ppm chromium, 0.02 ppm cadmium, 0.41 ppm barium, 0.01 ppm zinc, 0.01 ppm nickel, 1.2 ppm aluminum, 0.01 ppm silver, 0.001 ppm arsenic, 0.0002 ppm mercury, and 0.001 ppm selenium. All are well below the TCLP limits for each metal.

3 Results

Stabilization Techniques

Manufacturers use several techniques to stabilize HM within solid waste streams. These methods can be generalized in the following order of increasing preference:

1. The product contains a buffer to keep any contacting solution in a pH range (usually above pH 7) that minimizes metal leaching. In the short term, this buffer would defeat the TCLP test by altering the acidic pH of the extraction fluid. However, when the buffering capacity is gone, the product fails because there is no chemical interaction with the metal. A product containing only the buffering action to minimize or control the HM leaching is the least preferred option.
2. A vendor product mixed with the waste stream without a chemical reaction is a mixed dry procedure. Stabilization only occurs when a solution such as water or TCLP extract is introduced into the media. The liquid does two things: leaches out the HM and dissolves the added stabilization chemical, which allows a reaction to occur. This reaction produces a nonsoluble metal compound that precipitates out of solution. The key distinction is that the stabilization reaction occurs during the testing procedure or when the mixture encounters liquid in the environment. This type of treatment requires complete mixing of the product with the waste to ensure that all of the leached HM will react to produce an insoluble product. A second feature of this type of product may possibly be a buffering component, which serves to both minimize the HM leaching in the first place and create a pH environment in which the stabilized HM compound is most stable.
3. A vendor product that produces an immediate stabilization reaction usually includes a liquid as the mixing media. This process is preferable since the HM waste is stabilized during the treatment process (before the TCLP procedure) and is not merely buffered to circumvent the TCLP test outlined in Method 1 above.
4. S/S reactions create a nonsoluble form of metal that is then physically encapsulated to provide additional environmental protection. This technique provides maximum protection for the environment. The solidification step forces careful consideration of the end-product use for the waste and usually precludes in-situ uses.

A fifth method that includes extraction of the HM followed by recycle as a treatment process is beyond the scope of this work.

Stabilization Results

Although many of the standard wastes had a very high total metal concentration, the leachable amounts were surprisingly low. Few of these wastes provided a reasonable test for the stabilization products. The four TCLP wastes, CRM202, CRM203, CRM206, and CRM208, were better indicators of product performance. All data, however, are provided.

Tables 2 through 14 (shown relative to discussions of the particular samples) are the leachable metal results on the standard wastes. The row labeled "Certified Conc." is the certified data on each sample from RTC. CRM202, CRM203, CRM206, and CRM208 are leachable metal concentrations while all other standards are total metal concentrations. The row labeled "Untreated" is the leachable TCLP metal concentration from each sample before treatment as measured in this laboratory. Every other row is the leachable TCLP metal concentration from each sample after a stabilization treatment. Since some of the products add a significant amount of mass to the standard waste, all data have been corrected for dilution effects. Effectiveness of the vendor product is obtained by comparing the initial metal concentrations before treatment to the leachable metal concentrations after treatment. The pH column represents the pH of the TCLP extract solution after agitation. This column provides a measure of the treatment product's effect on the pH of the extraction fluid.

CRM018 Raw Sewage Sludge

Table 2 contains the data from the treatment of CRM018, standard raw sewage sludge. The CRM018 sample did not leach any metal of significant concentration except for aluminum (54.3 ppm). All of the waste treatments reduced the aluminum concentration in the leachate. However, the Portland cement, Cement 2, J, K, and M products did not perform as well. Since arsenic, selenium, and mercury concentrations in the control sample were well below TCLP limits, the samples of treated CRM018 were not analyzed for these volatile metals.

CRM006 Paint Sludge

Table 3 contains the data from the treatment of CRM006, standard paint sludge. CRM006 did not leach any HM of significant concentration except for zinc. The Portland cement that had a 1-day cure and Products A and C demonstrated a significant reduction (a factor of 100 or more) in the amount of zinc leached with the TCLP solution. The 1-day cured Portland cement and Product A exhibited a pH > 11, which may account for the lack of zinc leaching into TCLP extract. Portland cement that cured for 30 days exhibited a neutral pH of 7.1, and more zinc leached out. Interestingly, some of the treatments actually increased the concentration of zinc leaching into the solution. This result may be caused by the lack of sample homogeneity inherent in the paint sludge but is more likely due to an alteration in the sample chemistry by the vendor product. This effect was seen in several other samples as well. The concentration of barium in the control leachate was only 4.82 ppm, far lower than the 100 ppm TCLP limit. Several of the products reduced the barium concentrations below 1 ppm. Again the strong performance of the 1-day cured Portland cement may be contributed to the extract's high pH, since the 30-day cured sample with a lower pH value had a higher barium concentration. Some of the treatments also increased the leachable barium concentration. The danger now is that using these products, specifically Products H and I, to treat a different HM may actually create a hazardous waste by failing the TCLP for barium. Since arsenic, selenium, and mercury concentrations in the control sample were well below TCLP limits, the samples of treated CRM006 were not analyzed for these volatile metals.

Table 2. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of CRM018.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	126	40.1	5.57	72.1	6.63	1103	8.38	4.78	1,121	20.4	22,436
5.9	Untreated	<0.05	0.47	<0.02	0.19	0.06	1.70	<0.05	0.01	3.30	<0.01	54.3
9.9	Portland cement – 1-day cure	1.03	0.07	<0.02	<0.01	NT*	<0.41	NT	NT	0.50	0.25	10.3
6.9	Portland cement – 30-day cure	<0.05	<0.01	<0.02	0.09	NT	<0.41	NT	NT	0.69	0.51	7.9
7.1	Cement 2	<0.05	0.64	<0.02	<0.01	NT	<0.41	NT	NT	0.90	<0.01	23.3
11.5	A	<0.05	0.07	<0.02	0.02	NT	<0.41	NT	NT	0.19	<0.01	<1.2
5.7	B	<0.05	0.02	<0.02	0.02	NT	<0.41	NT	NT	0.23	<0.01	2.8
9.0	C	<0.05	0.02	<0.02	0.02	NT	<0.41	NT	NT	0.02	<0.01	2.6
8.8	D	<0.05	0.02	<0.02	0.02	NT	<0.41	NT	NT	3.85	<0.01	1.2
6.2	E	0.15	<0.01	<0.02	<0.01	NT	<0.41	NT	NT	0.19	0.07	1.9
6.0	F	0.31	<0.01	<0.02	<0.01	NT	<0.41	NT	NT	1.05	0.19	3.7
6.2	G	0.09	0.05	<0.02	<0.01	NT	<0.41	NT	NT	0.15	0.07	1.4
7.6	H	0.20	<0.01	<0.02	0.02	NT	<0.41	NT	NT	0.20	0.08	<1.2
7.1	I	0.18	0.16	<0.02	0.04	NT	<0.41	NT	NT	0.43	0.12	2.7
5.7	J	0.18	<0.01	<0.02	0.03	NT	<0.41	NT	NT	0.63	0.09	7.6
6.0	K	0.13	<0.01	<0.02	<0.01	NT	<0.41	NT	NT	0.41	0.03	5.1
6.0	L	0.61	<0.01	0.12	0.06	NT	NT	NT	NT	3.58	0.48	NT
5.9	M	0.15	<0.01	0.04	0.03	NT	0.85	NT	NT	0.26	0.05	5.2
6.2	N	0.27	0.11	0.04	0.11	NT	3.55	NT	NT	0.98	0.41	<1.2

* NT indicates the sample was not tested for that metal.

Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

Table 3. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of CRM006.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	753.0	11.1	32.4	-	-	9,969	-	-	737,431	-	73.4
6.6	Untreated	<0.05	<0.01	<0.02	<0.01	<0.05	4.82	<0.05	0.001	630	<0.01	0.3
11.1	Portland cement – 1-day cure	1.18	<0.01	<0.02	<0.01	NT*	0.85	NT	NT	0.56	<0.01	<1.2
7.1	Portland cement – 30-day cure	<0.05	<0.01	<0.02	<0.01	NT	1.92	NT	NT	40.00	0.35	<1.2
7.3	Cement 2	<0.05	0.41	<0.02	0.03	NT	<0.41	NT	NT	6.17	<0.01	<1.2
11.4	A	0.26	<0.01	<0.02	<0.01	NT	0.66	NT	NT	0.25	<0.01	<1.2
7.0	B	<0.05	0.01	<0.02	<0.01	NT	0.46	NT	NT	94.56	<0.01	<1.2
7.5	C	<0.05	0.02	<0.02	0.02	NT	<0.41	NT	NT	5.41	<0.01	<1.2
7.5	D	<0.05	0.01	<0.02	0.01	NT	<0.41	NT	NT	21.64	<0.01	<1.2
6.4	E	0.24	<0.01	<0.02	<0.01	NT	<0.41	NT	NT	347.6	<0.01	<1.2
7.0	F	0.24	<0.01	<0.02	<0.01	NT	<0.41	NT	NT	351.4	<0.01	<1.2
6.9	G	0.24	0.01	<0.02	<0.01	NT	<0.41	NT	NT	75.53	<0.01	<1.2
6.8	H	<0.05	<0.01	0.04	<0.01	NT	6.72	NT	NT	727.5	<0.01	1.2
6.5	I	<0.05	<0.01	0.04	<0.01	NT	11.13	NT	NT	939.4	<0.01	<1.2
6.1	J	<0.05	0.01	0.03	0.01	NT	4.17	NT	NT	701.2	<0.01	<1.2
6.7	K	<0.05	<0.01	0.02	<0.01	NT	4.28	NT	NT	695.8	<0.01	<1.2
6.8	L	<0.05	<0.01	0.02	<0.01	NT	3.25	NT	NT	494.3	<0.01	<1.2
6.6	M	0.05	<0.01	0.05	<0.01	NT	<0.41	NT	NT	860.2	0.03	<1.2
6.9	N	0.17	0.05	0.05	0.06	NT	0.90	NT	NT	423.1	0.27	<1.2

Note: No certified concentrations were given for silver, arsenic, selenium, mercury, or nickel.

* NT indicates the sample was not tested for that metal.

Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

CRM013 Paint Chips

Table 4 contains the data from the treatment of CRM013, a standard waste of paint chips. Without treatment, CRM013 leached chromium at 7.77 ppm, which is above the TCLP regulated amount of 5.00 ppm. Products E, F, and G reduced the chromium concentration below 0.1 ppm with only a 0.5 unit increase in pH. Products C, H, I, and N reduced the concentration below 2 ppm. Zinc was also present in the untreated TCLP leachate at a concentration of 13 ppm. In this case, Portland cement, Cement 2, and Products C and N reduced the zinc below 2.0 ppm. Since arsenic, selenium, and mercury concentrations in the control sample were well below TCLP limits, the samples of treated CRM013 were not analyzed for these volatile metals.

Table 4. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of CRM013.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	643.2	617.6	37.8	-	-	-	-	-	-	-	-
4.9	Untreated	0.20	7.77	0.56	<0.01	<0.05	0.74	<0.05	<0.0002	13.00	<0.01	<1.2
11.38	Portland cement – 1-day cure	1.17	10.14	<0.02	<0.01	NT*	1.26	NT	NT	<0.01	<0.01	2.1
10.1	Portland cement – 30-day cure	<0.05	9.37	<0.02	0.03	NT	2.126	NT	NT	<0.01	0.03	<1.2
7.0	Cement 2	0.33	4.10	<0.02	<0.01	NT	<0.41	NT	NT	<0.01	<0.01	17.0
11.6	A	0.99	20.62	<0.02	<0.01	NT	0.93	NT	NT	2.06	<0.01	3.0
5.3	B	0.20	5.52	0.37	0.01	NT	<0.41	NT	NT	2.07	0.16	<1.2
7.8	C	<0.05	1.49	<0.02	0.01	NT	<0.41	NT	NT	0.01	<0.01	<1.2
10.0	D	0.74	26.05	0.65	<0.01	NT	0.55	NT	NT	5.32	<0.01	1.6
5.4	E	0.30	0.03	<0.02	<0.01	NT	<0.41	NT	NT	6.66	<0.01	<1.2
5.4	F	0.34	0.06	<0.02	<0.01	NT	<0.41	NT	NT	6.36	<0.01	<1.2
5.3	G	1.20	<0.01	0.06	<0.01	NT	<0.41	NT	NT	11.54	<0.01	<1.2
5.7	H	0.25	1.15	0.39	0.02	NT	2.53	NT	NT	5.93	<0.01	1.4
5.2	I	0.49	1.85	1.18	0.02	NT	3.74	NT	NT	6.62	0.08	2.2
5.0	J	1.71	7.00	0.44	0.01	NT	1.98	NT	NT	15.25	0.09	<1.2
5.1	K	1.29	6.15	0.30	<0.01	NT	1.49	NT	NT	11.29	0.05	<1.2
5.1	L	0.15	6.98	0.05	0.01	NT	0.60	NT	NT	8.68	0.12	<1.2
4.9	M	0.17	2.97	0.47	<0.01	NT	<0.41	NT	NT	7.90	0.11	<1.2
5.4	N	0.20	0.64	0.06	0.03	NT	3.70	NT	NT	1.28	0.31	<1.2

Note: Certified concentrations were given for only lead, chromium, and cadmium.
* NT indicates the sample was not tested for that metal.
Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

CRM012 Ash From Industrial Incinerator

Table 5 contains the data from the treatment of CRM012, a standard ash sample from an industrial incinerator. The pH levels of these TCLP extracts were lower than any of the other standards, reflecting the acidic nature of the ash. CRM012 without treatment leached chromium (96.5 ppm) and cadmium (11.1 ppm) significantly above the TCLP limits of 5.00 ppm and 1.00 ppm, respectively. Only Product A reduced the chromium concentration to a level approaching the TCLP limit of 5 ppm. Again, many of the treatment products drastically increased the leachable chromium. The Portland cement, Cement 2, and Products A, C, and D substantially reduced the cadmium concentrations in the leachate.

CRM012 initial leachate also contained moderate amounts of the nonregulated metals: zinc, nickel, and aluminum. Only Product A dramatically reduced the nickel concentrations. Portland cement, Cement 2, and Products A, C, and D stabilized the zinc and aluminum; Product B, not quite as well. Since arsenic, selenium, and mercury concentrations in the control sample were well below

TCLP limits, the samples of treated CRM012 were not analyzed for these volatile metals.

Table 5. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of CRM012.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	120.1	161,517	361.6	54.8	-	18.7	-	-	634.7	13,279	2160
4.0	Untreated	0.20	96.51	11.07	0.20	<0.05	<0.41	0.13	<0.0001	17.50	51.08	16.5
6.3	Portland cement – 1-day cure	2.28	211.0	0.84	0.34	NT*	3.89	NT	NT	0.34	112.8	<1.2
6.2	Portland cement – 30-day cure	0.38	162.0	2.54	1.02	NT	0.96	NT	NT	0.47	217.2	<1.2
6.3	Cement 2	0.30	158.9	<0.02	0.83	NT	<0.41	NT	NT	0.12	19.00	<1.2
7.5	A	0.37	7.87	<0.02	0.37	NT	1.51	NT	NT	0.04	<0.01	1.9
4.4	B	0.28	120.5	7.15	0.15	NT	<0.41	NT	NT	7.91	41.22	6.9
5.8	C	0.64	28.33	1.94	0.40	NT	0.28	NT	NT	0.27	137.3	1.7
6.4	D	0.28	75.62	0.09	0.36	NT	<0.41	NT	NT	0.13	36.46	<1.2
4.4	E	0.57	44.36	12.16	0.25	NT	<0.41	NT	NT	18.16	66.23	20.1
4.5	F	0.56	42.86	12.69	0.21	NT	<0.41	NT	NT	16.52	67.69	18.4
4.5	G	0.60	43.38	11.07	0.01	NT	<0.41	NT	NT	14.00	70.42	13.9
4.9	H	0.58	<0.01	8.48	0.04	NT	1.07	NT	NT	9.00	76.40	6.6
4.7	I	0.39	<0.01	10.84	0.08	NT	0.57	NT	NT	12.15	77.99	7.6
4.7	J	0.50	35.89	12.28	0.19	NT	<0.41	NT	NT	16.66	56.96	18.1
4.1	K	0.50	35.86	12.33	0.22	NT	<0.41	NT	NT	18.70	62.34	19.8
4.2	L	0.55	39.39	13.29	0.09	NT	<0.41	NT	NT	17.51	68.99	18.5
4.1	M	0.51	1263	13.05	0.23	NT	0.43	NT	NT	10.04	79.19	11.8
4.4	N	0.93	221.1	14.83	0.29	NT	1.55	NT	NT	17.64	453.9	11.5

Note: No certified concentrations were given for arsenic, selenium, and mercury.

* NT indicates the sample was not tested for that metal.

Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

CRM020

Table 6 contains the data from the treatment of CRM020, a standard soil sample. Untreated CRM020 contained lead in the TCLP leachate at 4.3 ppm, which approaches the TCLP regulation limit of 5.0 ppm. All of the products reduced the amount of leachable lead, although Product I had the least effect. All products except Cement 2 and Product L also reduced aluminum concentrations. Many of the products had a destabilizing effect on zinc, increasing the leachable amount. Since arsenic, selenium, and mercury concentrations in the control sample were well below TCLP limits, the samples of treated CRM020 were not analyzed for these volatile metals.

Table 6. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of CRM020.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	5,111	13.6	15.4	38.5	400	24.8	6.57	1.12	3011	16.9	1,755
4.7	Untreated	4.30	0.02	0.36	0.03	0.23	<0.41	<0.05	<0.0001	3.30	0.02	10.3
9.8	Portland cement – 1-day cure	1.36	0.15	<0.02	<0.01	NT*	2.26	NT	NT	<0.01	0.29	3.5
9.3	Portland cement – 30-day cure	<0.05	0.15	<0.02	0.43	NT	3.30	NT	NT	0.03	0.34	<1.2
6.5	Cement 2	<0.05	0.80	<0.02	<0.01	NT	<0.41	NT	NT	2.09	<0.01	10.6
11.0	A	<0.05	0.13	<0.02	<0.01	NT	1.51	NT	NT	0.02	<0.01	<1.2
5.0	B	1.31	0.11	0.39	<0.01	NT	1.46	NT	NT	21.19	<0.01	4.6
15.0	C	0.17	0.04	<0.02	<0.01	NT	<0.41	NT	NT	0.03	2.73	1.7
9.5	D	<0.05	0.03	<0.02	<0.01	NT	<0.41	NT	NT	0.02	<0.01	2.0
5.2	E	0.46	<0.01	0.17	<0.01	NT	<0.41	NT	NT	77.79	<0.01	2.7
5.2	F	0.90	<0.01	0.23	<0.01	NT	<0.41	NT	NT	70.61	<0.01	2.7
5.4	G	0.54	0.22	<0.02	<0.01	NT	0.66	NT	NT	8.42	<0.01	<1.2
5.4	H	0.60	0.04	0.58	0.04	NT	<0.41	NT	NT	111.7	0.33	4.5
5.0	I	2.49	0.06	1.21	0.08	NT	<0.41	NT	NT	113.4	0.81	6.9
4.7	J	0.44	0.03	0.53	0.02	NT	<0.41	NT	NT	96.96	0.32	6.2
4.8	K	0.29	0.03	0.61	0.03	NT	<0.41	NT	NT	115.6	0.40	6.7
4.9	L	0.41	0.24	0.15	0.08	NT	<0.41	NT	NT	11.59	0.59	10.3
4.7	M	0.23	0.15	0.67	<0.01	NT	<0.41	NT	NT	12.02	0.38	7.8
5.1	N	0.33	0.06	0.10	0.03	NT	<0.41	NT	NT	74.46	0.78	6.2

* NT indicates the sample was not tested for that metal.
Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

CRM025

Table 7 contains the data from the treatment of CRM025, a standard soil sample. Untreated CRM025 leached cadmium (9.4 ppm) and selenium (9.6 ppm), which are above the TCLP limits (1.00 ppm for both metals). Portland cement, Cement 2, and Products A, C, and D reduced the leachable cadmium concentration to a level below 1 ppm. Products A, F, G, and L reduced the leachable selenium concentration to below 1 ppm. Untreated CRM025 also exhibited high levels of arsenic and mercury, although, not above the TCLP limits. About half of the treatment methods reduced the arsenic concentration but several increased the leachable arsenic concentration. Only Cement 2 was unable to decrease the leachable mercury concentration.

CRM202

Table 8 contains the data from the treatment of CRM202, a standard soil from a Superfund site. This sample was the first of the standard samples to have certified metal concentrations from TCLP testing. Untreated CRM202 leached lead, cadmium, silver, selenium, and mercury above the regulatory TCLP limits.

Many treatments would effectively stabilize some metals and not others. Leachable lead was reduced by all of the products, but six treatment products could not stabilize below the TCLP limit of 5 ppm. Only Cement 2 could not stabilize CRM202 to pass TCLP for silver. Portland cement, Cement 2, and Products A, C, and D can effectively treat cadmium. Products A, E, F, G, and L can reduce selenium below the TCLP limit of 1 ppm. Leachable mercury can be treated by Products F, H, I, J, K, and L. The other metals do not exceed TCLP limits. Because CRM202 contained high levels of several metals, a separate grouping of results is listed in Table 9 that rates the vendor products on how well they stabilized a particular metal. A value of 1 indicates the product is highly successful at stabilizing the metal well below the TCLP limit. A value of 2 means the product can stabilize the metal below the TCLP limit. A value of 3 means little if any stabilization occurred, and the final product would not pass TCLP. Finally, if a product has little effect on the metal or if it actually increases the amount that leaches, it receives a value of 4. Time constraints precluded testing of Products M and N for the ability to stabilize volatile metals. For the HM lead and cadmium, most of the 1s are localized near the top left of the table. For the volatile metals selenium and mercury, however, the 1s localize near the bottom right of the table. This result clearly indicates a choice in stabilization product can be made based upon contaminant volatility. In addition, no single product can effectively treat both types of metal.

Table 7. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of CRM025.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	1,447	441	369	132	339	1,839	518	99.8	51.8	12.2	7,637
5.6	Untreated	1.60	0.47	9.36	0.35	4.20	1.10	9.60	0.160	0.08	<0.01	3.7
11.2	Portland cement – 1-day cure	1.71	2.98	<0.02	<0.01	0.09	4.95	3.10	0.069	0.29	1.18	2.4
7.7	Portland cement – 30-day cure	<0.05	1.99	0.06	0.241	3.92	1.537	9.65	0.106	0.03	0.18	<1.2
7.0	Cement 2	<0.05	1.23	<0.02	1.40	11.32	7.23	15.98	0.303	0.20	<0.01	6.0
11.0	A	<0.05	1.14	<0.02	0.04	0.07	2.30	0.32	0.082	0.01	<0.01	1.7
5.3	B	<0.05	0.22	4.22	0.50	8.37	2.19	10.69	0.121	0.07	<0.01	1.2
9.1	C	<0.05	0.11	<0.02	0.17	0.50	2.49	4.11	0.069	0.01	<0.01	<1.2
10.0	D	<0.05	0.75	<0.02	0.06	<0.02	3.42	2.10	0.059	0.01	<0.01	<1.2
6.0	E	0.75	0.05	5.43	<0.01	0.02	0.43	1.06	0.006	0.17	0.14	<1.2
6.2	F	0.88	0.01	4.63	<0.01	0.02	<0.41	0.81	0.002	0.12	0.19	<1.2
6.4	G	0.60	<0.01	2.06	<0.01	0.02	<0.41	0.73	0.010	0.11	0.21	<1.2
6.3	H	0.91	0.06	9.96	0.41	12.25	2.37	19.76	0.003	0.34	0.04	2.8
6.0	I	1.00	0.08	7.78	0.44	6.19	1.80	10.97	0.008	0.22	0.04	2.0
5.8	J	2.38	0.14	7.98	0.03	4.06	0.79	5.84	0.007	0.15	0.05	<1.2
5.7	K	2.82	0.17	7.07	0.04	4.56	0.68	6.70	0.007	0.16	0.07	<1.2
5.9	L	0.51	0.24	2.48	0.03	7.20	0.70	0.46	0.004	0.12	0.02	<1.2
5.4	M	0.51	0.24	2.47	0.03	NT*	0.60	NT	NT	0.12	0.10	<1.2
6.3	N	1.01	0.59	10.96	0.41	NT	1.02	NT	NT	0.10	0.54	<1.2

* NT indicates the sample was not tested for that metal.

Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

Table 8. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of CRM202.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	48.54	11.10	19.61	5.01	1.44	5.85	1.38	5.58	-	-	-
5.3	Untreated	38.00	4.48	18.76	7.63	1.40	6.34	1.80	3.200	0.29	<0.01	7.7
11	Portland cement – 1-day cure	1.07	0.59	<0.02	<0.01	NT*	14.04	3.65	1.797	<0.01	0.84	2.2
9.3	Portland cement – 30-day cure	<0.05	0.214	<0.02	<0.01	NT	<0.41	4.28	1.897	0.061	0.25	<1.2
7.0	Cement 2	<0.05	6.01	<0.02	7.76	NT	<0.41	12.21	1.617	0.36	<0.01	15.8
11	A	<0.05	0.19	<0.02	0.07	NT	5.37	0.36	1.021	0.01	<0.01	<1.2
6.0	B	0.89	2.10	4.15	4.27	NT	<0.41	5.00	1.780	0.06	<0.01	3.0
7.4	C	<0.05	<0.01	<0.02	0.03	NT	<0.41	2.55	2.441	10.84	<0.01	1.9
9.8	D	<0.05	0.03	<0.02	0.34	NT	2.21	1.66	1.882	0.01	<0.01	1.2
5.3	E	14.21	1.13	15.01	0.20	NT	3.02	0.73	1.106	0.60	<0.01	6.4
5.6	F	7.44	0.36	15.08	<0.01	NT	<0.41	0.27	0.082	0.30	<0.01	<1.2
5.6	G	10.21	0.34	8.42	0.10	NT	2.00	0.25	0.590	0.30	0.10	3.0
5.9	H	4.75	1.08	17.46	0.36	NT	10.37	10.37	0.026	0.14	<0.01	1.2
5.7	I	9.80	0.77	20.87	2.91	NT	9.90	8.12	0.036	0.51	0.02	<1.2
5.5	J	21.86	3.02	15.33	0.04	NT	2.19	2.37	0.004	0.37	<0.01	<1.2
5.4	K	26.41	3.59	17.72	0.01	NT	2.79	1.99	0.001	0.58	<0.01	<1.2
5.6	L	2.73	1.95	5.88	0.02	NT	3.47	0.05	0.002	0.31	<0.01	<1.2
5.2	M	3.81	3.44	12.80	3.30	NT	0.69	NT	NT	0.11	0.06	<1.2
5.8	N	3.94	0.65	2.34	0.05	NT	2.93	NT	NT	0.17	0.38	<1.2

Note: No certified concentrations were given for zinc, nickel, and aluminum.
* NT indicates the sample was not tested for that metal.
Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

Table 9. Comparison of vendor products and stabilization efficiency for particular metals.

Sample	Pb	Cd	Ag	Se	Hg
Portland cement – 1-day cure	1	1	1	4	3
Portland cement – 30-day cure	1	1	1	4	3
Cement 2	1	1	4	4	3
A	1	1	1	1	3
B	1	3	2	4	3
C	1	1	1	4	3
D	1	1	1	3	3
E	3	4	1	1	3
F	3	4	1	1	2
G	3	3	1	1	3
H	2	4	1	4	2
I	3	4	2	4	2
J	3	4	1	4	1
K	3	4	1	4	1
L	2	3	1	1	1
M	2	3	2	NT*	NT
N	2	3	1	NT	NT

Legend: 1 = highly successful, 2 = some stabilization and below the TCLP limit, 3 = some stabilization but above the TCLP limit, and 4 = no stabilization
* NT indicates the sample was not tested for that metal.
Pb = lead; Cd = cadmium; Ag = silver; Se = selenium; Hg = mercury

CRM203

Table 10 shows the data from the stabilization of CRM203, a contaminated ash. The values reported by RTC are leachable metal concentrations from TCLP testing. Only lead and cadmium leached values above the TCLP limits. Since arsenic, selenium, and mercury had very low or no leaching from this ash, these samples were not sent out for volatile metal analysis. Similar to data from CRM202, the lead was stabilized by Portland cement, Cement 2, and Products A, B, C, and D. Portland cement, Cement 2, and Products A, B, C, and G could stabilize cadmium below TCLP limits.

Table 10. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of CRM203.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	14.3	<0.1	22.5	<0.01	<0.01	<0.5	<0.1	<0.001	-	-	-
5.2	Untreated	20.32	0.06	24.80	0.03	NT*	0.59	NT	NT	12.44	0.71	7.6
11.2	Portland cement – 1-day cure	0.23	0.45	0.16	0.04	NT	0.41	NT	NT	0.53	1.11	1.3
NT	Portland cement – 30-day cure	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
6.8	Cement 2	0.70	0.38	0.35	<0.01	NT	<0.41	NT	NT	2.37	0.06	<1.2
12.0	A	0.75	0.16	0.11	0.03	NT	<0.41	NT	NT	0.61	0.78	1.9
5.4	B	0.62	<0.01	10.62	0.03	NT	<0.41	NT	NT	12.10	0.41	<1.2
8.6	C	0.37	<0.01	0.08	0.04	NT	<0.41	NT	NT	<0.01	0.30	1.8
8.4	D	0.61	<0.01	1.75	0.02	NT	<0.41	NT	NT	0.71	0.27	<1.2
5.6	E	15.14	<0.01	12.60	0.02	NT	<0.41	NT	NT	13.37	0.45	1.7
5.6	F	23.08	<0.01	5.51	0.06	NT	<0.41	NT	NT	17.79	0.62	2.0
5.7	G	6.53	<0.01	0.16	0.13	NT	<0.41	NT	NT	13.21	0.40	1.7
5.9	H	8.85	<0.01	20.26	0.02	NT	0.43	NT	NT	24.03	1.24	<1.2
5.7	I	14.81	0.02	25.65	0.04	NT	0.62	NT	NT	23.72	1.56	1.3
5.5	J	22.92	0.06	17.26	0.02	NT	<0.41	NT	NT	12.02	0.79	6.0
5.4	K	22.94	0.06	3.10	0.03	NT	<0.41	NT	NT	12.01	0.77	4.8
5.5	L	19.02	0.02	2.13	0.02	NT	<0.41	NT	NT	11.97	0.80	4.0
5.3	M	5.96	0.42	20.84	0.02	NT	<0.41	NT	NT	13.11	0.28	1.2
5.7	N	4.97	0.09	3.58	0.05	NT	0.64	NT	NT	2.68	0.89	<1.2

Note: No certified values were given for zinc, nickel, or aluminum.

* NT indicates the sample was not tested for that metal.

Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

CRM206

Table 11 contains the data from the treatment of CRM206, a standard soil sample. Untreated CRM206 leached high concentrations of four metals: cadmium, arsenic, mercury, and selenium. Cadmium was stabilized by Portland cement, Cement 2, and Products C, D, and N. Portland cement and Products A, D, E, F, and G stabilized the arsenic below the TCLP regulatory limit of 5 ppm. Only Products A, G, and L stabilized selenium. As expected, mercury was treated effectively by the later products F, G, H, I, J, K, and L. Products M and N were not tested for stabilization of the volatile metals. Table 12 compiles the results on CRM206 for cadmium, arsenic, mercury, and selenium. The rankings in Table 12 have the same definition as those in Table 9, where a value of 1 is highly successful, down to a value of 4, which means little or no stabilization or even increased leaching. Again, the products that stabilize the nonvolatile metals are at the top of the table while those that can stabilize the volatile metals are at the bottom.

Table 11. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of CRM206.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	2.16	0.13	8.34	1.04	13.99	0.38	20.55	0.65	-	-	-
5.3	Untreated	1.70	0.18	6.89	0.91	14.00	0.30	17.00	1.10	0.15	<0.01	9.1
11.4	Portland cement – 1-day cure	1.14	0.50	<0.02	<0.01	0.23	2.92	5.55	0.85	<0.01	0.88	4.7
9.2	Portland cement – 30-day cure	<0.05	0.41	<0.02	0.12	2.87	2.13	8.28	0.71	<0.01	0.27	<1.2
7.0	Cement 2	<0.05	2.48	<0.02	2.34	18.81	<0.41	21.12	1.16	0.66	<0.01	21.8
10.0	A	<0.05	0.07	5.20	0.01	0.11	<0.41	0.92	0.56	0.03	<0.01	2.4
6.0	B	<0.05	<0.01	2.61	0.79	12.19	<0.41	17.73	0.68	0.07	<0.01	1.6
7.8	C	<0.05	<0.01	<0.02	0.22	7.38	<0.41	13.22	0.56	0.02	<0.01	<1.2
9.8	D	<0.05	0.01	<0.02	0.12	0.05	<0.41	5.62	0.56	0.02	<0.01	<1.2
5.3	E	1.24	0.01	8.27	0.10	0.15	<0.41	1.80	0.22	0.80	<0.01	3.2
5.4	F	0.69	<0.01	4.44	<0.01	0.04	<0.41	1.39	0.05	0.40	<0.01	1.4
5.7	G	0.48	<0.01	2.40	<0.01	0.04	<0.41	0.47	0.04	0.20	0.20	1.3
5.9	H	0.39	<0.01	4.15	0.41	13.65	0.78	21.44	0.01	<0.01	<0.01	1.2
5.7	I	7.72	0.52	7.92	1.25	15.31	8.06	28.21	0.02	1.01	0.04	1.6
5.3	J	1.46	<0.01	6.08	0.04	11.27	<0.41	13.00	0.09	0.07	<0.01	<1.2
5.3	K	2.12	<0.01	6.78	0.05	11.59	<0.41	13.52	0.05	0.07	<0.01	<1.2
5.6	L	0.76	0.02	3.21	1.13	12.81	<0.41	0.76	0.02	0.04	0.04	<1.2
5.3	M	0.57	<0.01	6.48	0.76	NT*	<0.41	NT	NT	0.11	0.03	<1.2
6.1	N	0.69	0.04	0.50	0.03	NT	1.83	NT	NT	0.09	0.39	<1.2

Note: No certified values were given for zinc, nickel, or aluminum.
* NT indicates the sample was not tested for that metal.
Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

CRM208

The leachable metal concentrations from treatment of CRM208 are given in Table 13. CRM208 is a contaminated soil that fails TCLP for cadmium and has an elevated level of barium. Portland cement, Cement 2, and Products A, C, D, L, and N effectively treat the cadmium. CRM208 has the highest level of leachable barium of any standard waste. Barium leachability is reduced by Portland cement, Cement 2, and Products C, E, F, G, M, and N.

Table 12. Comparison of vendor products and stabilization efficiency for particular metals.

Sample	Cd	As	Se	Hg
Portland cement – 1 day cure	1	1	3	3
Portland cement – 30 day cure	1	2	3	3
Cement 2	1	4	4	4
A	3	1	1	3
B	2	4	4	3
C	1	3	4	3
D	1	1	3	3
E	4	1	2	3
F	3	1	2	1
G	3	1	1	1
H	3	4	4	1
I	4	4	4	1
J	4	4	4	1
K	4	4	4	1
L	3	4	2	1
M	4	NT*	NT	NT
N	1	NT	NT	NT

Legend: 1 = highly successful, 2 = some stabilization and below the TCLP limit, 3 = some stabilization but above the TCLP limit, and 4 = little or no stabilization

* NT indicates the sample was not tested for that metal.

Cd = cadmium; As = arsenic; Se = selenium; Hg = mercury

Table 13. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of CRM208.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	2.14	0.87	46.7	ND*	3.93	32.8	ND	0.62	-	-	-
5.8	Untreated	0.49	1.37	30.88	0.02	NT**	32.10	NT	NT	0.01	0.40	<1.2
9.7	Portland cement – 1-day cure	<0.05	<0.01	<0.02	<0.01	NT	1.30	NT	NT	<0.01	<0.01	<1.2
NT	Portland cement – 30-day cure	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
6.8	Cement 2	1.03	8.63	0.44	<0.01	NT	<0.41	NT	NT	<0.01	0.06	3.8
11.4	A	0.08	3.59	0.08	0.03	NT	1.30	NT	NT	<0.01	0.54	<1.2
5.4	B	0.24	0.27	14.24	0.02	NT	2.20	NT	NT	0.05	0.08	<1.2
8.8	C	0.08	0.13	<0.02	0.01	NT	<0.41	NT	NT	<0.01	0.01	<1.2
9.5	D	0.09	4.86	<0.02	0.01	NT	7.10	NT	NT	<0.01	0.02	1.4
6.5	E	0.17	0.04	3.44	0.03	NT	<0.41	NT	NT	<0.01	0.20	<1.2
6.6	F	0.22	<0.01	3.01	0.02	NT	<0.41	NT	NT	<0.01	0.20	<1.2
6.5	G	0.20	<0.01	3.64	0.07	NT	0.50	NT	NT	<0.01	0.21	<1.2
6.7	H	0.88	0.02	19.12	0.02	NT	15.00	NT	NT	<0.01	0.74	<1.2
6.6	I	0.92	0.02	30.28	0.02	NT	15.60	NT	NT	<0.01	0.55	<1.2
6.0	J	0.40	0.25	21.05	0.02	NT	26.00	NT	NT	<0.01	0.41	<1.2
6.1	K	0.26	0.22	15.04	0.02	NT	28.00	NT	NT	<0.01	0.36	<1.2
6.4	L	0.38	0.27	0.12	0.02	NT	22.90	NT	NT	<0.01	0.36	<1.2
5.6	M	0.52	0.54	26.00	<0.01	NT	<0.41	NT	NT	0.01	0.05	<1.2
6.8	N	0.28	0.06	0.13	0.03	NT	<0.41	NT	NT	0.08	0.40	<1.2

Note: No certified concentrations were given for zinc, nickel, or aluminum.

* ND indicates the metal was not detected.

** NT indicates the sample was not tested for that metal.

Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

S2

Sample S2 is a "clean" soil with low levels of all metals. Table 14 shows that the total metal content of this soil is very low and the leachable metal concentration for each metal approaches the detection limit of the instrument. Stabilization work on this sample is primarily to demonstrate that the vendor products do not contribute an appreciable amount of a metal background to the TCLP results. As Table 14 shows, in only a few cases did the stabilized product leach more metal than the unstabilized sample.

Table 14. HM concentrations (ppm) for TCLP extracts of untreated and treated samples of S2.

pH	Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al
	Certified Conc.	ND*	ND	ND	ND	2.00	50.00	0.40	0.03	21.30	ND	3540
6.5	Untreated	0.28	0.04	0.03	0.03	NT**	0.60	NT	NT	0.01	0.48	<1.2
9.4	Portland cement – 1-day cure	0.24	0.43	0.06	0.04	NT	1.02	NT	NT	0.02	1.20	1.6
NT	Portland cement – 30-day cure	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
6.3	Cement 2	0.73	0.51	0.29	<0.01	NT	<0.41	NT	NT	<0.01	0.10	2.9
11.9	A	1.18	0.14	0.04	0.03	NT	1.18	NT	NT	0.01	0.74	<1.2
6.7	B	0.24	<0.01	0.03	0.01	NT	0.49	NT	NT	<0.01	0.20	<1.2
8.4	C	0.26	<0.01	0.02	0.01	NT	<0.41	NT	NT	<0.01	0.17	<1.2
9.8	D	0.19	<0.01	0.02	0.01	NT	<0.41	NT	NT	<0.01	0.16	<1.2
6.8	E	0.26	<0.01	0.02	0.02	NT	<0.41	NT	NT	<0.01	0.21	1.3
6.8	F	0.25	<0.01	0.03	0.06	NT	<0.41	NT	NT	<0.01	0.22	<1.2
6.9	G	0.35	0.19	0.09	0.18	NT	<0.41	NT	NT	0.02	0.08	<1.2
6.6	H	0.44	0.06	0.11	0.02	NT	0.42	NT	NT	0.02	1.04	<1.2
7.9	I	0.19	0.02	0.04	0.04	NT	<0.41	NT	NT	0.02	1.04	<1.2
7.2	J	0.09	0.02	0.03	0.02	NT	0.58	NT	NT	0.02	0.51	<1.2
7.2	K	0.10	0.04	0.03	0.04	NT	<0.41	NT	NT	0.01	0.49	<1.2
6.7	L	0.24	0.04	0.02	0.04	NT	<0.41	NT	NT	0.04	0.50	<1.2
6.2	M	0.32	0.28	0.10	0.01	NT	<0.41	NT	NT	<0.01	0.10	<1.2
6.9	N	0.45	0.06	0.09	0.04	NT	0.64	NT	NT	0.06	0.52	<1.2

* ND indicates the metal was not detected.

** NT indicates the sample was not tested for that metal.

Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

4 Discussion

All of the data for each standard waste product are summarized in Table 15. Table 15 represents the effectiveness of a vendor product to stabilize particular metals. The rankings are basically the average behavior for each product from the previous tables. When compiling the data in Table 15, metals that exceeded the TCLP limit were the only data used to evaluate vendor effectiveness.

Examination of the data in Table 15 shows that all of the vendor products effectively treated at least one metal (rank = 1). At the same time, no vendor product could treat every metal. Calculation of the average effectiveness of each vendor product across the range of metals yields a value that is termed Versatility. It is a measure of the number of metals a given product can stabilize well. In this case, lower versatility values indicate a wider range of metals that a product can treat. Clearly, some products can stabilize a wider range of metals than others. The versatility values range from 1.55 (Product A) to 3.09 (Products J and K).

Table 15. Vendor rankings for each particular metal averaged from all data.

Sample	Pb	Cr	Cd	Ag	As	Ba	Se	Hg	Zn	Ni	Al	Versatility
Portland cement – 1-day cure	2	4	1	1	1	1	3	3	1	4	2	2.09
Portland cement – 30-day cure	1	4	1	1	3	NT*	4	3	2	4	2	2.50
Cement 2	1	3	1	4	4	1	4	3	1	3	3	2.55
A	1	3	2	1	1	1	2	3	1	1	4	1.55
B	2	4	3	2	4	1	4	3	2	4	3	2.91
C	1	2	1	1	3	1	4	3	1	4	2	2.09
D	1	4	2	1	1	2	3	3	2	3	1	2.09
E	3	3	3	1	1	1	3	3	3	4	2	2.45
F	3	3	3	1	1	1	2	1	3	4	2	2.18
G	3	3	3	1	1	1	2	2	2	4	1	2.09
H	3	1	3	1	4	3	4	1	4	4	2	2.73
I	3	1	4	2	4	3	4	1	4	4	2	2.91
J	3	3	4	1	4	3	4	1	4	4	3	3.09
K	3	3	4	1	4	3	4	1	4	4	3	3.09
L	3	3	3	1	4	3	2	1	3	4	4	2.82
M	3	3	4	2	NT	1	NT	NT	4	4	3	3.00
N	2	3	3	1	NT	1	NT	NT	3	4	3	2.50
Stability Ease	2.24	2.94	2.65	1.35	2.67	1.69	3.27	2.13	2.59	3.71	2.47	

Legend: 1 = highly successful, stabilizing the metal substantially below the TCLP limit, 2 = some stabilization and below the TCLP limit, 3 = some stabilization but above the TCLP limit, and 4 = little or no stabilization.

* NT means Not Tested.

Pb = lead; Cr = chromium; Cd = cadmium; Ag = silver; As = arsenic; Ba = barium; Se = selenium; Hg = mercury; Zn = zinc; Ni = nickel; Al = aluminum

At the bottom of each metal column, the table also shows a variable termed Stability Ease, which is the average of the effectiveness rankings for each metal. The lower the number, the easier it is to stabilize that metal. Silver (1.35) and barium (1.69) were the easiest to treat, while nickel (3.71) and selenium (3.27) were the most difficult. Using this group of standard wastes, many vendor products received a ranking of 1 for stabilizing silver and barium. Only one product received a 1 for stabilization of nickel, and none ranked a 1 for selenium.

Apart from effectiveness and versatility, several other properties for successful HM stabilization treatment were evaluated (i.e., mass gain, ease of use, pH buffering capacity, and form of final product). Table 16 summarizes the evaluation of these parameters for the vendor products.

Mass Gain: Some products doubled or even tripled the original mass of the waste. Since disposal costs are calculated by mass, these treated materials will dramatically increase this expense. Generally, products that solidify as well as stabilize have the largest mass gain. As expected, Portland cement and Cement 2 tripled the sample weight. Low-level contaminated wastes treated with either Portland cement or Cement 2 may pass a TCLP test only as a result of a dilution effect.

Table 16. Summary of comparison between HM stabilization products.

Sample	Mass Gain	Effectiveness	pH	Ease of Use
Portland cement – 1-day cure	3	1	3	2
Portland cement – 30-day cure	3	2	3	2
Cement 2	3	2	2	2
A	2	1	3	2
B	1	3	1	1
C	1	1	2	1
D	1	1	3	1
E	2	2	1	3
F	2	1	1	3
G	2	1	1	3
H	2	2	1	1
I	2	3	1	1
J	1	3	1	2
K	1	3	1	2
L	1	2	1	2
M	1	3	1	2
N	1	2	1	2

Note: Products that increased the mass by 0-10 percent received a 1; a mass increase between 10-100 percent received a 2; and >100 percent mass increase received a 3.

Effectiveness: This column provides a generalization of the versatility column from Table 15. As a rough measure, vendor products with a versatility value of 2.2 or less received an effectiveness value of 1; a versatility value of 2.9 or above received an effectiveness value of 3.

pH: As stated in the introduction, some stabilization technologies rely on a buffer to reduce the metal leachability. The buffer is not preferred as, once the buffering capacity is lost, the material will fail and return to being a hazardous waste. Products that dramatically increase the pH received a value of 3, while those products with little effect on the pH received a value of 1.

Ease of Use: Products that are easier to use can be employed by the non-expert in the field and will provide less chance of user error. All of the products required thorough mixing for use. However, some vendor products required an addition of up to four chemicals for stabilization. Products requiring multiple steps and additions received a value of 3, while products receiving a 1 generally required only a single step.

A final comparison of stabilization reactions showed products that stabilize the metal during the treatment step are preferable to those that stabilize during the testing step. Five of the vendor products (B, C, D, H, and I) combine dry ingredients with the waste matrix. These products rely upon residual moisture in the waste or the addition of outside moisture (e.g., rainwater, TCLP extraction fluid, etc.) to effect stabilization. The remaining products react with the metal before testing.

5 Conclusions and Recommendations

The vendor products in this testing were used as received for stabilization of standard wastes with the generic procedure provided by the manufacturer. All vendors were willing to customize the product to the waste, but this avenue was not taken in order to provide measures of simplicity and versatility.

These tests showed that the stabilization can depend on a number of factors, including the initial amount of free metal available to leach, the form of the solid matrix, the total amount of all metals (co-contaminants), and the pH. This behavior stresses the need for complete testing of a stabilization product with a particular waste to evaluate the product's performance. Furthermore, because some treatments actually increased the leachability of some metals, all RCRA metals must be tested during product evaluation to ensure that, while treating one metal problem, a new metal leaching problem does not arise. It must be noted that choosing an appropriate treatment product also depends on several site factors, including the type of heavy metal contamination, type of solid wastes, and the state/local regulation determining disposal costs.

Portland cement worked quite well in many of these tests and must be given ample consideration as a treatment product. Due to their solidification properties, cements will not work as an in-situ technique. All other products have in-situ capability. A combination of a vendor product with cement may provide optimal environmental protection by combining a chemical reaction with physical encapsulation.

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14. ABSTRACT

Heavy metal (HM) contaminated waste is a major concern to Army and Department of Defense (DoD) installations due to the total volume and number of sites with this type of waste. The U.S. Environmental Protection Agency (EPA) strictly regulates the disposal and treatment of hazardous waste under the Resource Conservation and Recovery Act (RCRA), which classifies the HM-contaminated waste as hazardous by either definition (e.g., listed) or characteristic. By performing the Toxicity Characteristic Leaching Procedure (TCLP), wastes are tested to determine the leachable contaminant content to decide whether the samples fall within the strict EPA requirements for treatment of hazardous wastes.

The vendor products in this testing were used as received for stabilization of standard wastes with the generic procedure provided by the manufacturer. These tests showed that the stabilization can depend on a number of factors, including the initial amount of free metal available to leach, the form of the solid matrix, the total amount of all metals (co-contaminants), and the pH, stressing the need for complete testing of a stabilization product with a particular waste to evaluate the product's performance.

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